



(12) **United States Patent**
Gu et al.

(10) **Patent No.:** **US 9,337,278 B1**
(45) **Date of Patent:** **May 10, 2016**

(54) **GALLIUM NITRIDE ON HIGH THERMAL CONDUCTIVITY MATERIAL DEVICE AND METHOD**

H01L 29/205 (2013.01); *H01L 29/66462* (2013.01); *H01L 29/7787* (2013.01); *H01L 2224/32225* (2013.01); *H01L 2224/83192* (2013.01)

(71) Applicant: **TriQuint Semiconductor, Inc.**, Hillsboro, OR (US)

(58) **Field of Classification Search**

CPC *H01L 29/2003*; *H01L 29/66462*; *H01L 29/42316*; *H01L 29/7783*; *H01L 29/66431*; *H01L 29/802*; *H01L 29/7788*; *H01L 29/432*; *H01L 2924/13064*; *H01L 29/66318*
USPC 257/189, 192, 194, 196; 438/172, 191, 438/285, 604
See application file for complete search history.

(72) Inventors: **Xing Gu**, Plano, TX (US); **Jinqiao Xie**, Allen, TX (US); **Edward A. Beam, III**, Plano, TX (US); **Deep C. Dumka**, Richardson, TX (US); **Cathy C. Lee**, Allen, TX (US)

(73) Assignee: **TriQuint Semiconductor, Inc.**, Hillsboro, OR (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(56)

References Cited

U.S. PATENT DOCUMENTS

2014/0253241 A1* 9/2014 Lee *H03F 3/193* 330/277

OTHER PUBLICATIONS

Gao, Y., et al., "Etched Aperture GaN Cavet Through Photoelectrochemical Wet Etching," International Journal of High Speed Electronics and Systems, vol. 14, No. 1, 2004, pp. 245-264.

* cited by examiner

Primary Examiner — Hsien Ming Lee

(74) Attorney, Agent, or Firm — Withrow & Terranova, P.L.L.C.

(57)

ABSTRACT

Embodiments include but are not limited to semiconductor devices including a barrier layer, a gallium nitride channel layer having a Ga-face coupled with the barrier layer, and a thermoconductive layer having a thermal conductivity of at least 500 W/(m·K) within 1000 nanometers of a Ga-face of the gallium nitride channel layer. The semiconductor device may be a high-electron-mobility transistor or a semiconductor wafer. Methods for making the same also are described.

23 Claims, 5 Drawing Sheets

(21) Appl. No.: **14/631,677**

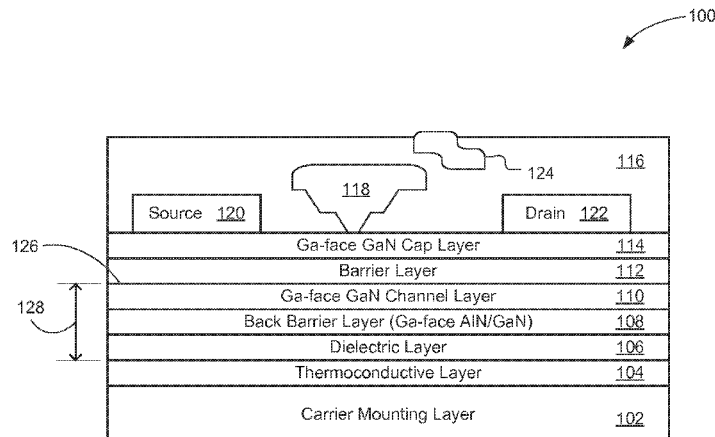
(22) Filed: **Feb. 25, 2015**

(51) **Int. Cl.**

H01L 21/338 (2006.01)
H01L 21/337 (2006.01)
H01L 21/336 (2006.01)
H01L 31/072 (2012.01)
H01L 29/739 (2006.01)
H01L 29/20 (2006.01)
H01L 29/205 (2006.01)
H01L 29/778 (2006.01)
H01L 23/367 (2006.01)
H01L 23/373 (2006.01)
H01L 21/02 (2006.01)
H01L 29/66 (2006.01)
H01L 23/00 (2006.01)
H01L 21/48 (2006.01)

(52) **U.S. Cl.**

CPC *H01L 29/2003* (2013.01); *H01L 21/0254* (2013.01); *H01L 21/4803* (2013.01); *H01L 23/367* (2013.01); *H01L 23/3732* (2013.01); *H01L 24/32* (2013.01); *H01L 24/83* (2013.01);



100

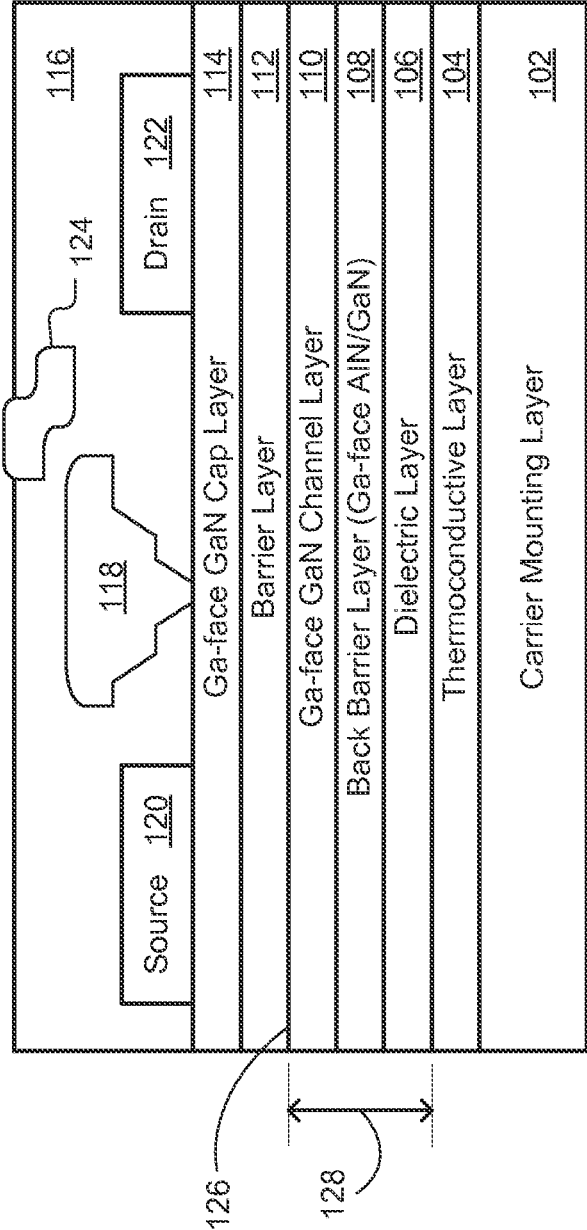


FIG. 1

200

Carrier Mounting Layer	222
Thermoconductive Layer	220
Dielectric Layer	218
Back Barrier Layer (N-face AlN/GaN)	216
N-face GaN Channel Layer	214
Barrier Layer	212
N-face GaN Layer	210
Release Layer	208
N-face GaN Buffer Layer	206
N-face Nucleation Layer	204
Substrate	202

FIG. 2

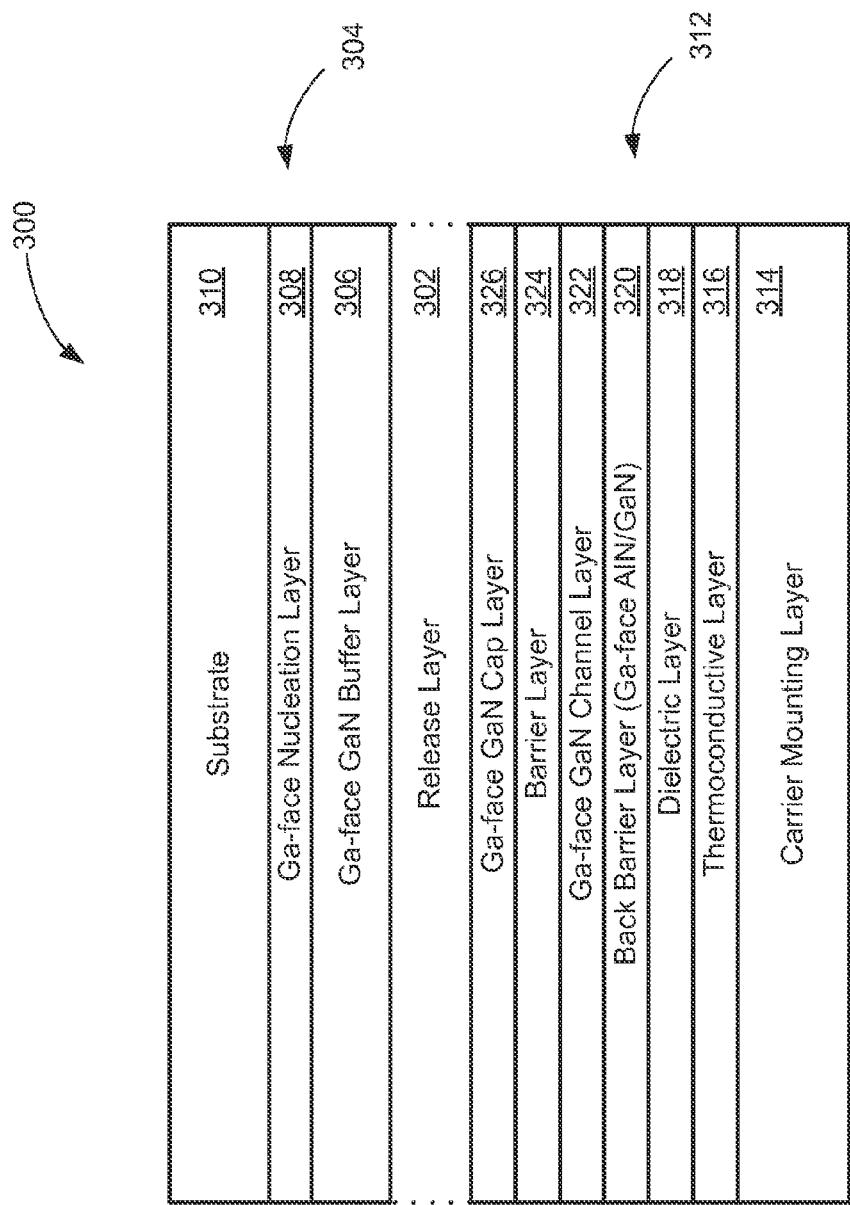


FIG. 3

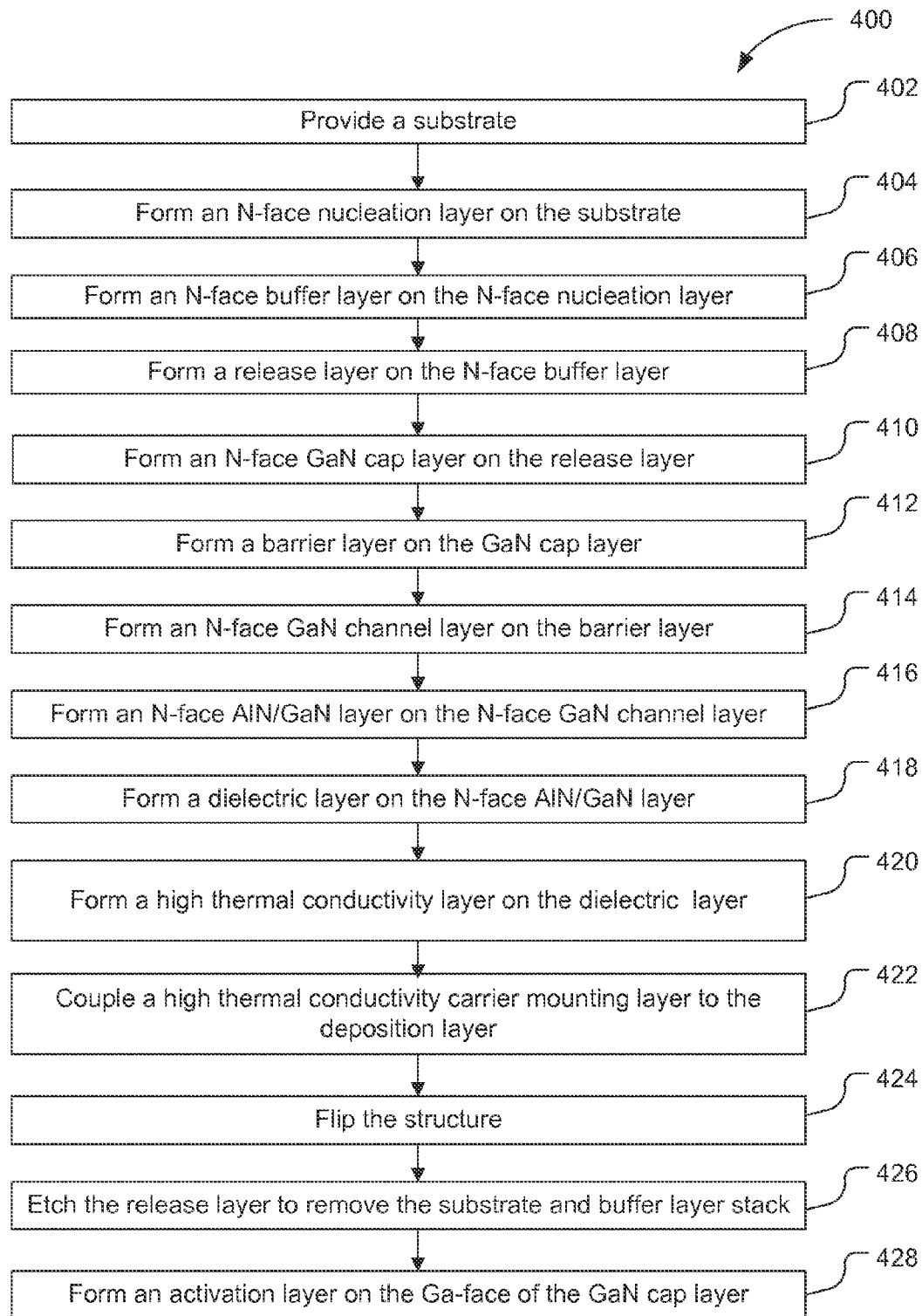


FIG. 4

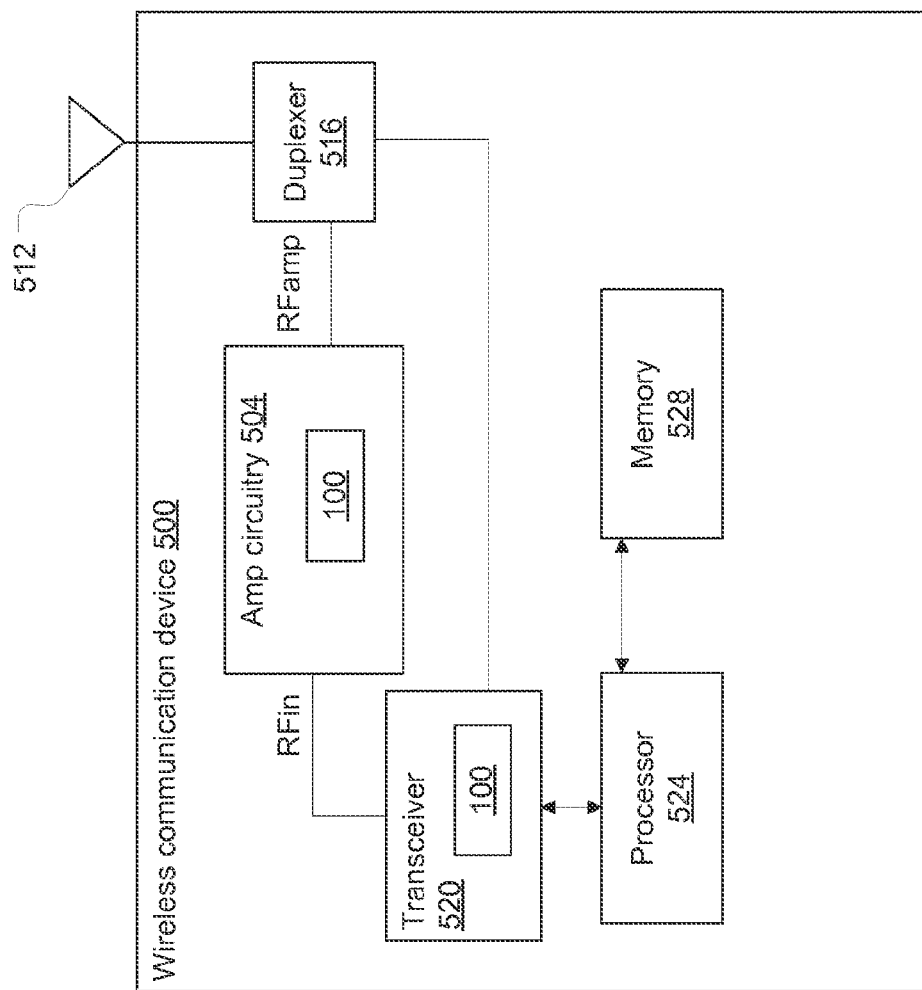


FIG. 5

1

GALLIUM NITRIDE ON HIGH THERMAL CONDUCTIVITY MATERIAL DEVICE AND METHOD

TECHNICAL FIELD

Embodiments of the present disclosure relate generally to gallium nitride (GaN) semiconductor devices and methods, and more particularly to GaN on high thermal conductivity material high electron mobility transistors (HEMTs).

BACKGROUND

In the current state of GaN semiconductor devices, the standard approach toward making GaN devices such as HEMTs, on a high thermal conductivity substrate (e.g., with thermal conductivity higher than silicon carbide (SiC)) has multiple limitations. The standard approach typically starts with a Ga-polar GaN device structure grown on Si-face SiC or a Si (111) substrate that is then flip-chip surface mounted to a carrier wafer. The SiC or Si substrate and part of a GaN buffer layer is then mechanically or chemically removed and replaced by a high thermal conductivity substrate such as diamond. The standard approach typically uses surface bonding to a carrier wafer that generates surface contamination that increases the possibility of high gate leakage current and large current collapse. The standard approach typically removes a substrate and a GaN buffer to expose the highly chemically active N-face of GaN to processing, which can lead to increased buffer leakage and reduced breakdown voltage. This may, in turn, limit the operation voltage of the device and its radio-frequency (RF) performance. The standard approach may also use a considerably thick GaN buffer layer that is retained due to process control limitations, which increases the distance between a junction of the device and the high thermal conductivity substrate which compromises the thermal dissipation performance of the device. The substrate is also typically attached to the active wafer by using an interfacial adhesive material with a significantly low thermal conductivity, which increases the thermal resistance of the device significantly.

BRIEF DESCRIPTION OF THE DRAWINGS

Embodiments of the present invention will be readily understood by the following detailed description in conjunction with the accompanying drawings. To facilitate this description, like reference numerals designate like structural elements. Embodiments of the invention are illustrated by way of example and not by way of limitation in the figures of the accompanying drawings.

FIG. 1 illustrates a cross-sectional view of a semiconductor device in accordance with various embodiments.

FIG. 2 illustrates a cross-sectional view of a multilayer wafer formed in accordance with various embodiments.

FIG. 3 illustrates a cross-sectional view of a multilayer wafer formed in accordance with various embodiments.

FIG. 4 is a flow diagram of a method for fabricating a semiconductor device in accordance with various embodiments.

FIG. 5 illustrates a block diagram of a system incorporating a semiconductor device, such as, for example, the semiconductor device illustrated in FIG. 1 in accordance with various embodiments.

DETAILED DESCRIPTION OF EMBODIMENTS OF THE INVENTION

Embodiments of the present disclosure describe gallium nitride (GaN) semiconductor devices and methods, and more

2

particularly GaN on high thermal conductivity material high electron mobility transistors (HEMTs). In the following detailed description, reference is made to the accompanying drawings which form a part hereof wherein like numerals designate like parts throughout, and in which is shown by way of illustration embodiments in which the invention may be practiced. It is to be understood that other embodiments may be utilized and structural or logical changes may be made without departing from the scope of the present invention. Therefore, the following detailed description is not to be taken in a limiting sense, and the scope of embodiments in accordance with the present invention is defined by the appended claims and their equivalents.

Various operations may be described as multiple discrete operations in turn, in a manner that may be helpful in understanding embodiments of the present invention; however, the order of description should not be construed to imply that these operations are order dependent. Moreover, some embodiments may include more or fewer operations than may be described.

The description may use the phrases “in an embodiment,” “in embodiments,” “in some embodiments,” or “in various embodiments,” which may each refer to one or more of the same or different embodiments. Furthermore, the terms “comprising,” “including,” “having,” and the like, as used with respect to embodiments of the present invention, are synonymous.

The phrase “coupled with,” along with its derivatives, may be used herein. “Coupled” may mean one or more of the following. “Coupled” may mean that two or more elements are in direct physical or electrical contact. However, “coupled” may also mean that two or more elements indirectly contact each other, but yet still cooperate or interact with each other, and may mean that one or more other elements are coupled or connected between the elements that are said to be coupled with each other.

The phrase “formed on,” along with its derivatives, may be used herein. “Formed on” in the context of a layer being “formed on” another layer may mean that a layer is formed above, but not necessarily in direct physical or electrical contact with, another layer (e.g., there may be one or more other layers interposing the layers). In some embodiments, however, “formed on” may mean that a layer is in direct physical contact with at least a portion of a top surface of another layer. Usage of terms like “top” and “bottom” are to assist in understanding, and they are not to be construed to be limiting on the disclosure.

The term “active surface” as used herein may refer to the surface of a die having the active regions/areas, as is known to those having skill in the art. The active surface of a die may include any one or more of various circuitry components, such as transistors, memory cells, passive components, and the like.

For the purposes of the present invention, the phrases “A or B” and “A and/or B” mean (A), (B), or (A and B).

A cross-sectional side view of an example semiconductor device **100** is illustrated in FIG. 1. As illustrated, the semiconductor device **100** (also referred to as “device **100**”) may include a Ga-face wafer stack including a carrier mounting layer **102**, a thermoconductive layer **104**, a dielectric layer **106**, a back barrier layer **108** that may be a Ga-face aluminum nitride (AlN)/GaN layer or an aluminum gallium nitride (Al-GaN) alloyed layer with Al composition from 1 to 100% in various embodiments, a Ga-face GaN channel layer **110**, a barrier layer **112**, and a Ga-face GaN cap layer **114**. In embodiments, the barrier layer **112** may be a Ga-face AlGaN layer, an indium aluminum nitride (InAlN) layer, or a related

alloy layer. In embodiments, the back barrier layer **108** may include at least one AlN layer and at least one GaN layer, or an AlGaIn alloyed layer with Al composition from 1 to 100%. In some embodiments, the back barrier layer **108** may include a plurality of AlN layers and a plurality of GaN layers arranged in an alternating fashion. An activation layer **116** may be formed on the Ga-face GaN cap layer **114** in various embodiments and include a material such as silicon nitride (SiN). In embodiments, Ga-face layers of the Ga-face wafer stack may have a Ga-face that faces away from the carrier mounting layer **102** toward the activation layer **116**. The activation layer **116** may include a gate **118**, a source **120**, and a drain **122** in various embodiments. The activation layer **116** may also include a field plate **124**. In embodiments, a two dimensional electron gas (2DEG) region **126** may be formed at an interface of the Ga-face GaN channel layer **110** and the barrier layer **112** from polarization and piezoelectric strain effects between these layers. The thermoconductive layer **104** may be within a distance **128** of 5 to 1000 nanometers (nm) from the 2DEG region **126** in various embodiments.

In various embodiments, one or more of the layers, such as the carrier mounting layer **102**, the dielectric layer **106**, the back barrier layer **108**, or the Ga-face GaN cap layer **114** may not be present. In embodiments, the thermoconductive layer **104** has a thermal conductivity, k value, of at least 500 watts per meter kelvin (W/(m·K)). The thermoconductive layer **104** may be a layer formed of diamond, boron nitride, graphene, graphite, or cubic boron arsenide in various embodiments. The carrier mounting layer **102** may have a similar thermal conductivity and composition as the thermoconductive layer **104** in various embodiments.

In embodiments, the device **100** includes an activation layer that is used in a high-electron-mobility transistor (HEMT). In other embodiments, differing types of activation layers for other device types may be used. In embodiments, an activation layer may not be present, with the device **100** being a multilayer wafer semiconductor component for use in later fabrication processes.

FIG. 2 illustrates a cross-sectional view of an N-face wafer stack **200** in accordance with various embodiments. The N-face wafer stack **200** may include a substrate **202**, an N-face nucleation layer **204**, an N-face GaN buffer layer **206**, a release layer **208**, an N-face GaN layer **210**, a barrier layer **212**, an N-face GaN channel layer **214**, a back barrier layer **216**, that may be an N-face AlN/GaN layer in various embodiments, a dielectric layer **218**, a thermoconductive layer **220**, and a carrier mounting layer **222**. In embodiments, the barrier layer **212** may be an N-face barrier layer such as an N-face AlGaIn layer, an N-face InAlN layer, or a related alloy layer. In embodiments, the back barrier layer **216** may include at least one N-face AlN layer and at least one N-face GaN layer. In some embodiments, the back barrier layer **216** may include a plurality of N-face AlN layers and a plurality of N-face GaN layers arranged in an alternating fashion, or an N-face AlGaIn alloyed layer with Al composition from 1 to 100%. In embodiments, N-face layers of the N-face wafer stack **200** may have an N-face that faces away from the substrate **202**. In various embodiments, one or more of the layers, such as the release layer **208**, the N-face GaN layer **210**, the back barrier layer **216**, the dielectric layer **218**, or the carrier mounting layer **222**, may not be present.

In embodiments, the substrate **202** may be a C-face silicon carbide (SiC) substrate, but other materials such as N-face GaN, N-face AlN, silicon, or sapphire may also be used. The release layer **208** may be an indium gallium nitride (InGaIn) layer having a thickness of approximately 10 nm to 100 nm and a composition of approximately 1% to 100% indium (In)

in various embodiments. The dielectric layer **218** may range in thickness from approximately 0 nm to 50 nm in various embodiments and may be formed of a material such as AlN. Other materials may be used for the release layer **208** or the dielectric layer **218** in other embodiments.

FIG. 3 illustrates a cross-sectional view of a Ga-face wafer stack **300** in accordance with various embodiments. The Ga-face wafer stack **300** may be a flipped N-face wafer stack **200** as described with respect to FIG. 2, in various embodiments. As shown, the Ga-face wafer stack **300** includes a release layer **302** partially etched to remove the release layer **302**, a substrate **310**, and a buffer stack **304** that may include a Ga-face GaN buffer layer **306** and a Ga-face nucleation layer **308**. In embodiments, Ga-face layers of the Ga-face wafer stack **300** may have a Ga-face that faces toward the substrate **310**. After removal of the release layer **302**, the substrate **310**, and the buffer stack **304**, a Ga-face GaN wafer stack **312** remains. The Ga-face GaN wafer stack **312** may include a carrier mounting layer **314**, thermoconductive layer **316**, dielectric layer **318**, back barrier layer **320**, that may be a Ga-face AlN/GaN layer in various embodiments, Ga-face GaN channel layer **322**, barrier layer **324**, and Ga-face GaN cap layer **326**. In embodiments, the back barrier layer **320** may include at least one AlN layer and at least one GaN layer. In some embodiments, the back barrier layer **320** may include a plurality of AlN layers and a plurality of GaN layers arranged in an alternating fashion. In embodiments, the back barrier layer **320** may include an N-face AlGaIn alloyed layer with Al composition from 1 to 100%. In various embodiments, the barrier layer **324** may be a Ga-face barrier layer, such as a Ga-face AlGaIn layer. In embodiments where the barrier layer **324** is formed of a material such as InAlN that does not contain Ga, the barrier layer **324** may be other than a Ga-face barrier layer. In various embodiments, one or more of the layers, such as the back barrier layer **320**, may not be present. In embodiments, Ga-face layers of the Ga-face GaN wafer stack **312** may have a Ga-face that faces away from the carrier mounting layer **314**. In embodiments, the Ga-face GaN wafer stack **312** corresponds to the portion of the device **100** below the activation layer **116** as shown in FIG. 1, with layers **102**, **104**, **106**, **108**, **110**, **112**, and **114** corresponding to layers **314**, **316**, **318**, **320**, **322**, **324**, and **326**, respectively.

In embodiments, layers **310**, **308**, **306**, **302**, **326**, **324**, **322**, **320**, **318**, **316**, and **314** of the wafer stack **300** may correspond to layers **202**, **204**, **206**, **208**, **210**, **212**, **214**, **216**, **218**, **220**, and **222**, respectively, of the wafer stack **200**. Accordingly, their characteristics and whether a given layer may not be present in some embodiments will not be further described as these matters have been discussed with respect to FIG. 2.

FIG. 4 illustrates a flow diagram of a method **400** for fabricating a semiconductor device such as the device **100** in accordance with various embodiments. In embodiments, various layers may be formed or grown, such as by using molecular beam epitaxy (MBE) or metal organic chemical vapor deposition (MOCVD), for example. In embodiments, some layers may be coupled with other layers using other methods, such as a bonding process for example. Generally, in embodiments, an inverted N-face GaN epitaxial structure may be used as a starting material with a high thermal conductivity material such as diamond deposited or bonded to a front side of the epitaxial structure, in an N-face GaN approach to fabricating the device. In embodiments, this allows the high thermal conductivity material to be made very close to a junction of the device, leading to a reduction in thermal resistance in comparison to devices produced by previous methods, and may increase power handling capability. The N-face GaN approach also may protect the N-face

GaN from harsh processing operations in comparison to previous methods, resulting lower buffer leakage.

At a block **402**, a substrate, such as substrate **202** or **310** may be provided. In embodiments, the substrate may be C-face SiC, N-face GaN, N-face AlN, silicon, sapphire, or another substrate. At operation **404**, an N-face nucleation layer, such as the N-face nucleation layer **204**, may be formed on the substrate. At a block **406**, an N-face buffer layer, such as the N-face GaN buffer layer **206**, may be formed on the N-face nucleation layer. At operation **408**, a release layer, such as the release layer **208** or **302**, may be formed on the N-face buffer layer. In embodiments, the release layer may include InGaN or InGaN-based multiple quantum wells. At a block **410**, an N-face GaN cap layer, such as the N-face GaN layer **210**, may be formed on the release layer. At operation **412**, a barrier layer, such as the barrier layer **212** that may be an N-face barrier layer such as an N-face AlGaIn layer in various embodiments, may be formed on the GaN cap layer. In embodiments, the barrier layer may be formed on or coupled with a different layer, such as with the release layer if the GaN cap layer is not included or with the N-face buffer layer if both the GaN cap layer and the release layer are not included, for example. At a block **414**, an N-face GaN channel layer, such as the N-face GaN channel layer **214**, may be formed on the barrier layer such that a Ga-face of the N-face GaN channel layer is coupled with the barrier layer. Generally, in embodiments, operations performed at the blocks **404-414** may include growth of an epitaxial layer stack using a growth technique such as MBE or MOCVD, for example. At operation **416**, a back barrier layer such as the back barrier layer **216** that may be an AlGaIn layer or an AlN/GaN layer, such as an N-face AlN/GaN layer, may be formed on the N-face GaN channel layer. In embodiments, the N-face AlN/GaN layer may be deposited in-situ to protect the N-face GaN material from exposure to air. In embodiments, the back barrier layer may be formed by forming at least one AlN layer and at least one GaN layer, with some embodiments forming the back barrier layer by forming a plurality of AlN layers and a plurality of GaN layers in an alternating fashion.

At a block **418**, a dielectric layer, such as the dielectric layer **218**, may be formed on the N-face AlN/GaN layer. At operation **420**, a high thermal conductivity layer, such as the thermoconductive layer **220**, may be formed on the dielectric layer. The high thermal conductivity layer may be formed by deposition, or alternatively may be placed on the epitaxial stack by bonding, in various embodiments. In embodiments, the high thermal conductivity layer may be grown by chemical vapor deposition (CVD) and may have a thickness between approximately 1 micrometers (μm) and 100 μm . In embodiments, the high thermal conductivity layer may be formed on or coupled with the back barrier layer if the dielectric layer is not included or the N-face GaN channel layer if both the dielectric layer and the back barrier layer are not included. At a block **422**, a high thermal conductivity carrier mounting layer, such as the carrier mounting layer **222**, may be coupled with the high thermal conductivity layer. In embodiments, the high thermal conductivity layer may have a thickness such as approximately 100 μm (or greater) such that the carrier mounting layer is not used.

At operation **424**, the wafer structure formed by the preceding operations may be flipped. In embodiments, the high thermal conductivity carrier mounting layer is now the substrate, with the overlying GaN/AlGaIn material having Ga-face polarity facing upward. The original substrate may now be on the top of the structure. At a block **426**, the release layer may be etched to remove the substrate and buffer layer stack and expose a Ga-face of the GaN cap layer. In embodiments,

a photo-assisted electrochemical wet etch may be applied to etch the release layer to remove the substrate and buffer layer stack. After lift-off of the substrate and buffer layer stack, a thin GaN layer formed at the block **410** may be present on the top of the structure that may prevent the AlGaIn layer from oxidation, followed by the AlGaIn layer formed at operation **412** and the GaN channel layer formed at the block **414**. A 2DEG may be formed at the interface between the AlGaIn layer and the GaN channel layer due to spontaneous polarization and piezoelectric polarization. The high thermal conductivity layer and high thermal conductivity carrier mounting layer may be below, and may be separated from the layers above by only a thin dielectric transition layer formed at the block **418** in various embodiments. At operation **428**, an activation layer, such as the activation layer **116**, may be formed on the Ga-face of the GaN cap layer.

As discussed with respect to FIG. 2, one or more of the layers of the process **400** may not be formed in various embodiments, such as the release layer, the N-face GaN layer, the back barrier layer, the dielectric layer, or the carrier mounting layer, for example. Accordingly, one or more of the operations of the process **400** may not be performed, such as forming an N-face GaN cap layer at the block **410**, forming the back barrier layer at operation **416**, forming the dielectric layer at the block **418**, or coupling a high thermal conductivity carrier mounting layer to the thermoconductive layer at the block **422**, for example. In such embodiments, subsequent layers described as being formed on or coupled with a particular layer with respect to the process **400** may be formed on or coupled with a different layer when the layer to which they are described as being formed on or coupled with was not formed. In embodiments, layers formed during the process **400** may be coupled directly with the layer they are formed on or bonded with.

The device **100** may be incorporated into any of a variety of apparatuses and systems. The device **100** may be used as a discrete transistor, included in a switch or amplifier, or be included as part of a monolithic microwave integrated circuit (MMIC), for example. A block diagram of an exemplary wireless communication device **500** incorporating device **100** is illustrated in FIG. 5. The wireless communication device **500** may include amplification circuitry **504**, antenna structure **512**, a duplexer **516**, a transceiver **520**, a processor **524**, and a memory **528** coupled with each other at least as shown. The wireless communication device **500** may include the device **100** incorporated into one or more of the components such as, but not limited to, amplification circuitry **504**, or transceiver **520**. While the wireless communication device **500** is shown with transmitting and receiving capabilities, other embodiments may include wireless communication devices without receiving or transmitting capabilities.

In various embodiments, the wireless communication device **500** may be, but is not limited to, a mobile phone, a paging device, a personal digital assistant, a text-messaging device, a portable computer, a desktop computer, a telecommunications base station, a subscriber station, an access point, a radar, a satellite communication device, or any other device capable of wirelessly transmitting radio-frequency (RF) signals.

The processor **524** may execute a basic operating system program, stored in the memory **528**, in order to control the overall operation of the wireless communication device **500**. For example, the processor **524** may control the reception of signals and the transmission of signals by transceiver **520**. The processor **524** may be capable of executing other pro-

cesses and programs resident in the memory 528 and may move data into or out of memory 528, as desired by an executing process.

The transceiver 520 may receive outgoing data (e.g., voice data, web data, e-mail, signaling data, etc.) from the processor 524, may generate an RFin signal to represent the outgoing data, and provide the RFin signal to the amplification circuitry 504.

The amplification circuitry 504 may amplify the RFin signal in accordance with a selected amplification mode. The amplified RFamp signal may be forwarded to the duplexer 516 and then to the antenna structure 512 for an over-the-air (OTA) transmission.

In a similar manner, the transceiver 520 may receive an incoming OTA signal from the antenna structure 512 through the duplexer 516. The transceiver 520 may process and send the incoming signal to the processor 524 for further processing.

In various embodiments, the antenna structure 512 may include one or more directional and/or omnidirectional antennas, including, e.g., a dipole antenna, a monopole antenna, a patch antenna, a loop antenna, a microstrip antenna or any other type of antenna suitable for OTA transmission/reception of RF signals.

Those skilled in the art will recognize that the wireless communication device 500 is given by way of example and that, for simplicity and clarity, only so much of the construction and operation of the wireless communication device 500 as is necessary for an understanding of the embodiments is shown and described. Various embodiments contemplate any suitable component or combination of components performing any suitable tasks in association with wireless communication device 500, according to particular needs. Moreover, it is understood that the wireless communication device 500 should not be construed to limit the types of devices in which embodiments may be implemented.

EXAMPLES

Some non-limiting examples include:

Example 1 may include a semiconductor component comprising: a barrier layer; a gallium nitride (GaN) channel layer having a Ga-face coupled with the barrier layer; and a thermoconductive layer within 1000 nanometers of the Ga-face of the GaN channel layer, wherein the thermoconductive layer has a thermal conductivity value of at least 500 W/(m·K) and is closer to an N-face of the GaN channel layer than to the Ga-face of the GaN channel layer.

Example 2 may include the subject matter of Example 1, further comprising: a dielectric layer between the GaN channel layer and the thermoconductive layer.

Example 3 may include the subject matter of any one of Examples 1-2, further comprising: a thermoconductive carrier mounting layer coupled with the thermoconductive layer, wherein the thermoconductive carrier mounting layer has a thermal conductivity value of at least 500 W/(m·K).

Example 4 may include the subject matter of any one of Examples 1-3, further comprising: a GaN cap layer, wherein the GaN cap layer is coupled with the barrier layer.

Example 5 may include the subject matter of any one of Examples 1-4, further comprising: a back barrier layer between the GaN channel layer and the thermoconductive layer.

Example 6 may include the subject matter of Example 5, further comprising a dielectric layer between the back barrier layer and the thermoconductive layer.

Example 7 may include the subject matter of any one of Examples 4-6, further comprising an activation layer coupled with a Ga-face of the GaN cap layer, the activation layer including a gate, a source, and a drain.

Example 8 may include the subject matter of any one of Examples 1-7, further comprising a thermoconductive carrier mounting layer coupled with the thermoconductive layer, wherein the thermoconductive carrier mounting layer has a thermal conductivity value of at least 500 W/(m·K).

Example 9 may include the subject matter of Example 8, wherein the thermoconductive layer and the thermoconductive carrier mounting layer are formed of a diamond based material.

Example 10 may include the subject matter of any one of Examples 1-9, wherein the thermoconductive layer is within 500 nanometers of the Ga-face of the GaN channel layer.

Example 11 may include a method of fabricating a semiconductor component comprising: forming an N-face barrier layer; forming an N-face gallium nitride (GaN) channel layer on the N-face barrier layer; and forming a thermoconductive layer within 1000 nanometers of the N-face GaN channel layer, wherein the thermoconductive layer has a thermal conductivity of at least 500 W/(m·K).

Example 12 may include the subject matter of Example 11, further comprising before forming the N-face barrier layer, forming an N-face GaN cap layer, wherein the N-face barrier layer is formed on the N-face GaN cap layer.

Example 13 may include the subject matter of Example 12, further comprising: providing a substrate; forming an N-face nucleation layer on the substrate before forming the N-face GaN cap layer; forming an N-face buffer layer on the N-face nucleation layer, wherein the N-face GaN cap layer is formed above the N-face buffer layer; and removing the substrate, N-face nucleation layer, and N-face buffer layer to expose a Ga-face of the N-face GaN cap layer.

Example 14 may include the subject matter of Example 13, further comprising forming a release layer on the N-face buffer layer, wherein forming the N-face GaN cap layer above the N-face nucleation layer includes forming the N-face GaN cap layer on the release layer, and wherein removing the substrate, N-face nucleation layer, and N-face buffer layer includes etching the release layer.

Example 15 may include the subject matter of any one of Examples 11-14, further comprising forming a back barrier layer on the N-face GaN channel layer.

Example 16 may include the subject matter of Example 15, further comprising forming a dielectric layer on the back barrier layer, wherein forming the thermoconductive layer includes forming the thermoconductive layer on the dielectric layer.

Example 17 may include the subject matter of any one of Examples 11-16, further comprising coupling a thermoconductive carrier mounting layer to the thermoconductive layer, wherein the thermoconductive carrier mounting layer has a thermal conductivity of at least 500 W/(m·K).

Example 18 may include the subject matter of any one of Examples 13-17, further comprising forming an activation layer on the Ga-face of the N-face GaN cap layer, the activation layer including a gate, a source, and a drain.

Example 19 may include the subject matter of any one of Examples 11-15, further comprising forming a dielectric layer above the N-face GaN channel layer, wherein forming the thermoconductive layer includes forming the thermoconductive layer on the dielectric layer.

Example 20 may include the subject matter of any one of Examples 11-15, further comprising forming a dielectric layer on the N-face GaN channel layer, wherein forming the

thermoconductive layer includes forming the thermoconductive layer on the dielectric layer.

Example 21 may include the subject matter of any one of Examples 11-17, further comprising forming an activation layer on a Ga-face of the N-face GaN cap layer, the activation layer including a gate, a source, and a drain.

Example 22 may include the subject matter of any one of Examples 11-21, wherein the thermoconductive layer is formed of diamond, boron nitride, graphene, graphite, or cubic boron arsenide.

Example 23 may include the subject matter of any one of Examples 13-19, wherein the thermoconductive layer is formed of diamond, the N-face nucleation layer is formed of aluminum nitride (AlN), and the N-face buffer layer is formed of GaN.

Example 24 may include semiconductor component prepared by a process comprising: forming an N-face barrier layer; forming an N-face gallium nitride (GaN) channel layer on the N-face barrier layer; and forming a thermoconductive layer within 1000 nanometers of the N-face GaN channel layer, wherein the thermoconductive layer has a thermal conductivity of at least 500 W/(m·K).

Example 25 may include the subject matter of Example 24 wherein the process further comprises: providing a substrate; forming an N-face nucleation layer on the substrate; forming an N-face buffer layer on the N-face nucleation layer; forming an N-face GaN cap layer above the N-face buffer layer, wherein the N-face barrier layer is formed on the N-face GaN cap layer; removing the substrate, N-face nucleation layer, and N-face buffer layer to expose a Ga-face of the N-face GaN cap layer; and forming an activation layer on the Ga-face of the N-face GaN cap layer, the activation layer including a gate, a source, and a drain.

Although certain embodiments have been illustrated and described herein for purposes of description of the preferred embodiment, it will be appreciated by those of ordinary skill in the art that a wide variety of alternate and/or equivalent embodiments or implementations calculated to achieve the same purposes may be substituted for the embodiments shown and described without departing from the scope of the present invention. Those with skill in the art will readily appreciate that embodiments in accordance with the present invention may be implemented in a very wide variety of ways. This application is intended to cover any adaptations or variations of the embodiments discussed herein. Therefore, it is manifestly intended that embodiments in accordance with the present invention be limited only by the claims and the equivalents thereof.

What is claimed is:

1. A semiconductor component comprising:
 - a barrier layer;
 - a gallium nitride (GaN) channel layer having a Ga-face coupled with the barrier layer; and
 - a thermoconductive layer within 1000 nanometers of the Ga-face of the GaN channel layer, wherein the thermoconductive layer has a thermal conductivity value of at least 500 W/(m·K) and is closer to an N-face of the GaN channel layer than to the Ga-face of the GaN channel layer.
2. The semiconductor component of claim 1, further comprising:
 - a dielectric layer between the GaN channel layer and the thermoconductive layer.
3. The semiconductor component of claim 1, further comprising:
 - a thermoconductive carrier mounting layer coupled with the thermoconductive layer, wherein the thermoconduc-

tive carrier mounting layer has a thermal conductivity value of at least 500 W/(m·K).

4. The semiconductor component of claim 1, further comprising:

a GaN cap layer, wherein the GaN cap layer is coupled with the barrier layer.

5. The semiconductor component of claim 4, further comprising:

a back barrier layer between the GaN channel layer and the thermoconductive layer.

6. The semiconductor component of claim 5, further comprising a dielectric layer between the back barrier layer and the thermoconductive layer.

7. The semiconductor component of claim 6, further comprising an activation layer coupled with a Ga-face of the GaN cap layer, the activation layer including a gate, a source, and a drain.

8. The semiconductor component of claim 7, further comprising a thermoconductive carrier mounting layer coupled with the thermoconductive layer, wherein the thermoconductive carrier mounting layer has a thermal conductivity value of at least 500 W/(m·K).

9. The semiconductor component of claim 8, wherein the thermoconductive layer and the thermoconductive carrier mounting layer are formed of a diamond based material.

10. The semiconductor component of claim 1, wherein the thermoconductive layer is within 500 nanometers of the Ga-face of the GaN channel layer.

11. A method of fabricating a semiconductor component comprising:

forming an N-face barrier layer;

forming an N-face gallium nitride (GaN) channel layer on the N-face barrier layer; and

forming a thermoconductive layer within 1000 nanometers of the N-face GaN channel layer, wherein the thermoconductive layer has a thermal conductivity of at least 500 W/(m·K).

12. The method of claim 11, further comprising before forming the N-face barrier layer, forming an N-face GaN cap layer, wherein the N-face barrier layer is formed on the N-face GaN cap layer.

13. The method of claim 12, further comprising:

providing a substrate;

forming an N-face nucleation layer on the substrate before forming the N-face GaN cap layer;

forming an N-face buffer layer on the N-face nucleation layer, wherein the N-face GaN cap layer is formed above the N-face buffer layer; and

removing the substrate, N-face nucleation layer, and N-face buffer layer to expose a Ga-face of the N-face GaN cap layer.

14. The method of claim 12, further comprising forming a dielectric layer on the N-face GaN channel layer, wherein forming the thermoconductive layer includes forming the thermoconductive layer on the dielectric layer.

15. The method of claim 12, further comprising forming an activation layer on a Ga-face of the N-face GaN cap layer, the activation layer including a gate, a source, and a drain.

16. The method of claim 12, wherein the thermoconductive layer is formed of diamond, boron nitride, graphene, graphite, or cubic boron arsenide.

17. The method of claim 13, further comprising forming a release layer on the N-face buffer layer, wherein forming the N-face GaN cap layer above the N-face nucleation layer includes forming the N-face GaN cap layer on the release

layer, and wherein removing the substrate, N-face nucleation layer, and N-face buffer layer includes etching the release layer.

18. The method of claim 13, further comprising forming a dielectric layer above the N-face GaN channel layer, wherein forming the thermoconductive layer includes forming the thermoconductive layer on the dielectric layer. 5

19. The method of claim 13, wherein the thermoconductive layer is formed of diamond, the N-face nucleation layer is formed of aluminum nitride (AlN), and the N-face buffer layer is formed of GaN. 10

20. The method of claim 17, further comprising forming a back barrier layer on the N-face GaN channel layer.

21. The method of claim 20, further comprising forming a dielectric layer on the back barrier layer, wherein forming the thermoconductive layer includes forming the thermoconductive layer on the dielectric layer. 15

22. The method of claim 21, further comprising coupling a thermoconductive carrier mounting layer to the thermoconductive layer, wherein the thermoconductive carrier mounting layer has a thermal conductivity of at least 500 W/(m·K). 20

23. The method of claim 22, further comprising forming an activation layer on the Ga-face of the N-face GaN cap layer, the activation layer including a gate, a source, and a drain.

* * * * *